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Higgs decay into two photons from a 3HDM with flavor symmetry.

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In this short letter we show that the excess of events in the decay of Higgs to two photons reported by ATLAS and CMS can be easily accommodated in a flavor renormalizable three Higgs doublet model (3HDM). The model is consistent with all fermion masses, mixing angles, and flavor changing neutral current constraints.

Recent results by ATLAS and CMS suggest an excess in the decay $H \to \gamma\gamma$ with respect to the Standard Model (SM) expectation [1, 2]. Since the coupling of the Higgs to photons is radiative one possible reason for the excess, without changing the rest of the decays, is the existence of new charged particles with masses of hundreds of GeV. On the other hand there does not seem to be any significant deviation in the gluon fusion rate nor in the decay rates of the Higgs into gauge bosons, therefore the new particles responsible for the excess on the rate to photons have to be colorless and preferably not spin 1, in order to avoid any mixing with the W or the Z. Thus it seems that the existence of one or more spin 0 or spin 1/2 charged particles could explain the diphoton rate measured at the LHC.

In this short letter we show that it is possible to accommodate the excess in the diphoton rate within a renormalizable three Higgs doublet model (3HDM) whose motivation is to describe, in a minimal way, the flavor structure of the SM. Having extra Higgs doublets imply, upon electroweak symmetry breaking, the existence of new charged spin zero particles, two in this particular model. We are going to show that it is possible to satisfy all flavor constrains in this model as well as to generate an extra contribution to the decay rate of the Higgs to photons due to the two new charged degrees of freedom.

The model: We explore a renormalizable flavor model based on the cyclic group Z_5 that contains three Higgs doublets. We chose Z_5 as it has been shown to be the smallest Abelian symmetry that in the context of 3HDM leads to the Nearest Neighbour Interaction (NNI) Yukawa textures in the quark sector [3]. Furthermore, the lepton sector of the model completely reproduces the one described in [4], where no right-handed neutrinos are introduced and neutrino Majorana masses are generated radiatively through the presence of an SU(2) singlet field charged under both Hypercharge and Lepton number.

The model particle content consists of the Standard Model fermion fields, three SU(2) doublets (Hypercharge $y = 1/2$) called $\mathcal{H} = (H, \Phi_1, \Phi_2)$, and a singlet scalar field η with Hypercharge $y = -1$ and Lepton number $L = 2$. The Z_5 charge assignments for the fermion fields are given by

$$\overline{Q}_L \simeq \overline{L}_L \simeq (0, -3, -1), \quad u_R \simeq d_R \simeq e_R \simeq (3, 0, 2), \tag{1}$$

where Q_L and L_L denote the quark and lepton left-handed SU(2) doublet SM fields respectively, while u_R, d_R, and e_R denote the quark and charged lepton right-handed SU(2) singlet SM fields. The scalar sector assignments are given by

$$\mathcal{H} \equiv (H, \Phi_1, \Phi_2) \simeq (0, -1, 1), \quad \eta \simeq (-1). \tag{2}$$

These assignments lead to NNI textures for the quarks and charged lepton Yukawa matrices, while the neutrino mass matrix is of the form

$$M_\nu = \begin{pmatrix} A & B & C \\ B & 0 & 0 \\ C & 0 & D \end{pmatrix}. \tag{3}$$

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The scalar potential for $\mathcal{H}$ is given by (see Eq. (12) of [3])

$$\begin{aligned} V(H,\Phi_a) &= \mu_0^2|H|^2 + \mu_a^2|\Phi_a|^2 + \mu_{0a}^2\left(\Phi_a^\dagger H + h.c\right) + \mu_{12}^2\left(\Phi_1^\dagger\Phi_2 + h.c\right) + \lambda_0\left(|H|^2\right)^2 \\ &+ \lambda_a\left(|\Phi_a|^2\right)^2 + \lambda_{0a}|H|^2|\Phi_a|^2 + \lambda_{12}|\Phi_1|^2|\Phi_2|^2 + \tilde{\lambda}_{ab}|\Phi_a^\dagger\tilde{\Phi}_b|^2 + \lambda'_{0a}\Phi_a^\dagger H H^\dagger\Phi_a \\ &+ \lambda_3\left(\Phi_1^\dagger H \Phi_2^\dagger H + h.c\right), \end{aligned} \tag{4}$$

where $a = 1,2$ and the terms proportional to μ_{0a} and μ_{12} are Z_5 soft breaking terms required in order to obtain the correct electromagnetic invariant vacuum. The scalar η in the model plays its role in the neutrino sector where it provides the necessary Lepton number violation in order to generate Majorana masses. Due to its heavy mass and small mixing, it does not play a role in the phenomenology of the charged scalars present in $\mathcal{H}$. When the diagonalization of the scalar sector is performed we thus only consider the potential in Eq. (4).

As discussed in [3, 4] the textures obtained in this model can reproduce all the observed masses and mixing angles in the quark and charged lepton number sectors, as well as the squared mass differences (for inverted hierarchy only) and mixing angles in the neutrino sector. Furthermore, it was also shown in [3] that the model is able to satisfy the strong flavor changing neutral current constraints coming from $K-\overline{K}$ mixing.

Results: A numerical scan of the parameter space of the model was performed in order to find regions where the model successfully reproduces/satisfies i) all quark masses and mixing angles, ii) charged lepton masses, squared neutrino mass differences and lepton mixing angles, iii) FCNC bounds from $\overline{K}-K$ mixing.

The regions that satisfy all these constraints are then used to determine the contribution to the decay of the lightest neutral CP-even scalar, h^0 into two photons. This decay is computed using the expression [6]

$$|M|^2 = \frac{g^2 m_H^2}{32\pi^2 m_W^2}\left|\sum_i \alpha N_c e_i^2 F_i\right|^2 , \tag{5}$$

where i runs over scalars, fermions and vector bosons in the loop with charge e_i and color factor N_c, and where the F_i factors are given by

$$F_0 = \left[\tau(1-\tau(\tau))\right] G_{abc} \tag{6}$$

$$F_{1/2} = \left[-2\tau(1+(1-\tau)f(\tau))\right] G_{abc} \tag{7}$$

$$F_1 = \left[2+3\tau+3\tau(2-\tau)f(\tau)\right] G_{abc} , \tag{8}$$

with $\tau \equiv (2m_i/m_H)^2$,

$$f(\tau) = \begin{cases} \left[\sin^{-1}(\sqrt{(1/\tau)}\right]^2 & \text{if } \tau \geq 1 \\ -\frac{1}{4}\left[\log\left(\frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}}\right) - i\pi\right]^2 & \text{if } \tau < 1 , \end{cases} \tag{9}$$

and where the factors G_{abc} contain the model dependent information on mixing angles and couplings among fields a, b and c in the diagram vertices ($G_{abc} = 1\ \forall\ a,b,c$ for the SM).

Following [7] we define the ratio

$$R_{\gamma\gamma} \equiv \frac{\mathrm{BR}(h^0\to\gamma\gamma)^{\mathrm{MODEL}}}{\mathrm{BR}(h^0\to\gamma\gamma)^{\mathrm{SM}}} \tag{10}$$

and take the best value for $R_{\gamma\gamma}$ obtained by combining in average the measurements presented in [1, 2, 8, 9]

$$R_{\gamma\gamma} = 2.1 \pm 0.5 . \tag{11}$$

The most recent results from ATLAS [10] quote a somewhat smaller ratio given by $R_{\gamma\gamma} = 1.8 \pm 0.3$ with $m_h = 126.6$ GeV, whereas CMS has not presented any update in this channel.

Figure 1 shows the values obtained for $R_{\gamma\gamma}$ as a function of the vacuum expectation value of H - v_0 - for three different sets of the parameters in the potential that satisfy the above conditions. Sets 1 and 2 correspond to cases where there are solutions that fall within a σ of the best value in (11) (shaded region with horizontal gray lines. The vertical green lines shade the region corresponding to the new ATLAS results) for some values of v_0 (Set 2 contains some points where the value of $R_{\gamma\gamma}$ falls outside). Set 3 on the other hand corresponds to a case where the model can give the same contribution than the SM and this happens for values of $v_0 \sim 233-236$ GeV. The specific values for the parameter in the potential for each of the shown sets are given in Table I. Note that in particular Set 1 falls within the intersection of the two regions.

	λ_1	λ_0	λ_{01}	λ_{02}	λ_{12}	$\tilde{\lambda}_{12}$	$\tilde{\lambda}_{21}$	λ'_{01}	λ'_{02}	λ_3	λ_2
Set 1	−0.3782	0.0721	0.9473	−0.2372	−0.1784	0.5587	0.2107	0.2954	0.4455	0.2098	0.3632
Set 2	0.9429	−0.1628	0.7062	−0.3952	−0.6729	−0.0983	−0.2106	0.3305	0.2143	0.5857	0.4335
Set 3	−0.3169	0.2017	−0.9434	0.4305	0.9398	0.2024	−0.6206	−0.1603	0.8452	−0.0159	0.7997

Table I: Three sets of parameter values consistent with current experimental data on fermion masses and mixing angles and FCNC contributions to $\overline{K}-K$ mixing. The ratio $R_{\gamma\gamma}$ obtained from these parameters as a function of the vev v_0 of H are shown in Figure 1. The vevs v_1 and v_2 are obtained by requiring the lightest neutral CP-even scalar to have a mass of $m_h = 125$ GeV and from the relation $\sum_i v_i^2 = (246)^2$ as v_0 is varied in Figure 1. The soft braking parameters are taken to be $\mu_{12}^2 = -(350)^2$, $\mu01^2 = -(400)^2$, and $\mu_{02}^2 = -(450)^2$.

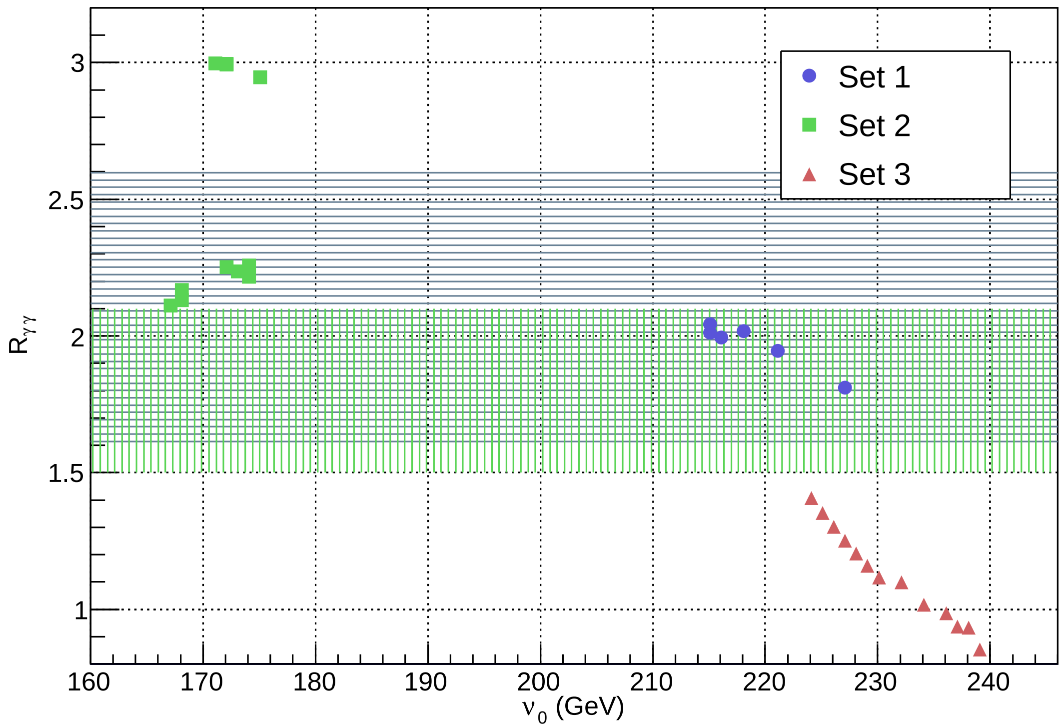

Figure 1: Contribution to $R_{\gamma\gamma}$ as a function of v_0 for three different sets of parameters. All points in the plot correspond to cases that reproduce all fermion masses and mixing angles as well as FCNC bounds from $\overline{K}-K$ mixing. The specific values for the parameters in the potential are given for each set are given in Table I. The shaded regions correspond to the 1 σ range of $R_{\gamma\gamma}$ as given by (11) (gray horizontal lines) and the latest ATLAS results (green vertical lines).

In this letter we considered the recent diphoton rate excess presented by ATLAS and CMS in the context of a renormalizable flavor model with three Higgs doublets and based on Z_5. We found that the model can accommodate the observed excess as well as all flavor observables including constraints from FCNC.

Acknowledgments

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